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A framework for identifying and selecting long term adaptation policy directions for deltas

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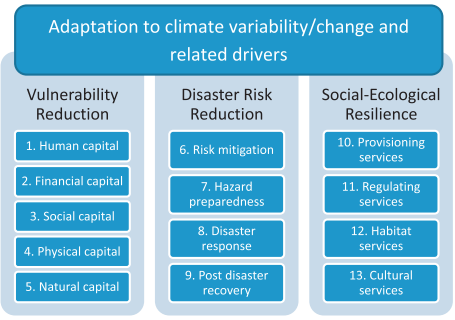
HIGHLIGHTS

- We generate a set of observed adaptations that are occurring in three deltas.
- We offer a framework for categorising adaptations into 13 distinct classes.
- Four future directions for adaptation policy focus on different classes of adaptation.
- Future policy directions range from minimum intervention to radical transformation.
- Countries can select a policy direction that suits their normative goals.

GRAPHICAL ABSTRACT



The 13 classes of adaptation

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ABSTRACT

Deltas are precarious environments experiencing significant biophysical, and socio-economic changes with the ebb and flow of seasons (including with floods and drought), with infrastructural developments (such as dikes and polders), with the movement of people, and as a result of climate and environmental variability and change. Decisions are being taken about the future of deltas and about the provision of adaptation investment to enable people and the environment to respond to the changing climate and related changes. The paper presents a framework to identify options for, and trade-offs between, long term adaptation strategies in deltas. Using a three step process, we: (1) identify current policy-led adaptations actions in deltas by conducting literature searches on current observable adaptations, potential transformational adaptations and government policy; (2) develop narratives of future adaptation policy directions that take into account investment cost of adaptation and the extent to which significant policy change/political effort is required; and (3) explore trade-offs that occur within each policy direction using a subjective weighting process developed during a collaborative expert workshop. We conclude that the process of developing policy directions for adaptation can assist policy makers in scoping the spectrum of options that exist, while enabling them to consider their own willingness to make significant policy changes within the delta and to initiate transformative change.

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1. Introduction

Deltas are dynamic, stressed and often densely populated environments. They are especially vulnerable to the impacts of climate change and variability, including sea-level rise, erosion, land loss, increased soil salinity, and changing storms (Church et al., 2013; Collins et al., 2013). These factors combined with subsidence and sediment starvation are rapidly changing the coastal landscape (Brown and Nicholls, 2015; Syvitski and Saito, 2007). This has implications for deltaic populations who rely on the economic activities and ecosystems services that deltas provide (Ericson et al., 2006). Without adaptation measures to address these multiple stresses, deltas could struggle to attain the Sustainable Development Goals (SDGs) and become unsafe locations. Human interventions have a long history in deltas through efforts to enhance livelihoods and reduce hazards. Engineered adaptation interventions, where they have occurred, have arguably had a major impact on delta evolution (Welch et al., 2017). However, these adaptations have not been systematically planned, assessed or documented to date. Consequently, there is a pressing need for information about what deltaic communities and their governments can do to adapt. Drawing on evidence of policy-led adaptations collected through a five year IDRC funded project ('Deltas, Vulnerability & Climate Change: Migration and Adaptation' - DECCMA) this paper aims to provide policy makers with insight into plausible adaptation policy directions in deltas. DECCMA's geographical focus is on three deltas in Africa and Asia: the Volta in Ghana, the Mahanadi in India, and the Ganges-Brahmaputra-Meghna (GBM) spanning India and Bangladesh (Fig. 1). However, this paper has a wider relevance, especially for large ecosystems, as we seek to generate a method for understanding adaptation in complex social and physical environments.

Adaptation policy is a newly emerging area for most countries where it is becoming an increasingly important challenge to meet. Adaptation is all the more pertinent in the context of the Paris Agreement 2015, the global agreement to address climate change, adopted under the United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement introduces an "ambition mechanism" requiring countries to strengthen their commitments to adaptation and mitigation. Many countries are grappling with the possible contents of adaptation policy, and this is especially challenging in large interconnected and transboundary ecosystems, such as deltas, mountains or coasts, where adaptation policies do not exist. Using deltas as an example, we reflect on the challenges affecting large ecosystems, that often have both upstream and downstream areas, and that may span national or regional borders. The aim of this paper is therefore to explore long term adaptation policy choices for deltas. To do this we ask: (1) what adaptations are occurring in deltas?; (2) what are possible future directions for adaptation policy?; and (3) what are the trade-offs associated with each policy direction?

This paper first reviews the theoretical literature on framing adaptation, and considers the key drivers underpinning adaptation policy development (Section 2). Drawing on data collected by DECCMA researchers during literature searches, inventory analysis and policy analysis, we then outline the planned, policy-led adaptations that are currently occurring in deltas, as well as presenting a method to create and populate four discrete directions for adaptation policy, which considers the trade-offs between different aspects of adaptation (Section 3). Section 4 describes specific adaptation actions in DECCMA's three deltas, in the context of the four directions for policy, which range from a minimum intervention approach to radical transformational adaptation.

2. Adaptation theory

Broadly defined, adaptation is "an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007). However, debates surrounding more precise definitions as well as the content of adaptation continue unabated adding to the perceived complexity of understanding adaptation (Lesnikowski et al., 2016). Despite the lack of consensus in answering questions about the relationship between adaptation and other variables e.g. coping and adapting, or adaptation and development, progress has been made on agreeing its broad aims. It is generally agreed that adaptation aims to: (1) address drivers of vulnerability; (2) reduce disaster risk (DRR); and, (3) build landscape/ecosystem resilience (Eakin et al., 2009; Ensor and Berger, 2009; McGray et al., 2007). These three broad aims allow a simpler categorisation of adaptation options and an easier communication to stakeholders. We are thus developing and organising our policy adaptation scenarios around these categories.

Well-developed theoretical constructs already exist to allow us to explore the three aims of adaptation in more detail. To better understand the first aim, addressing the drivers of vulnerability, the

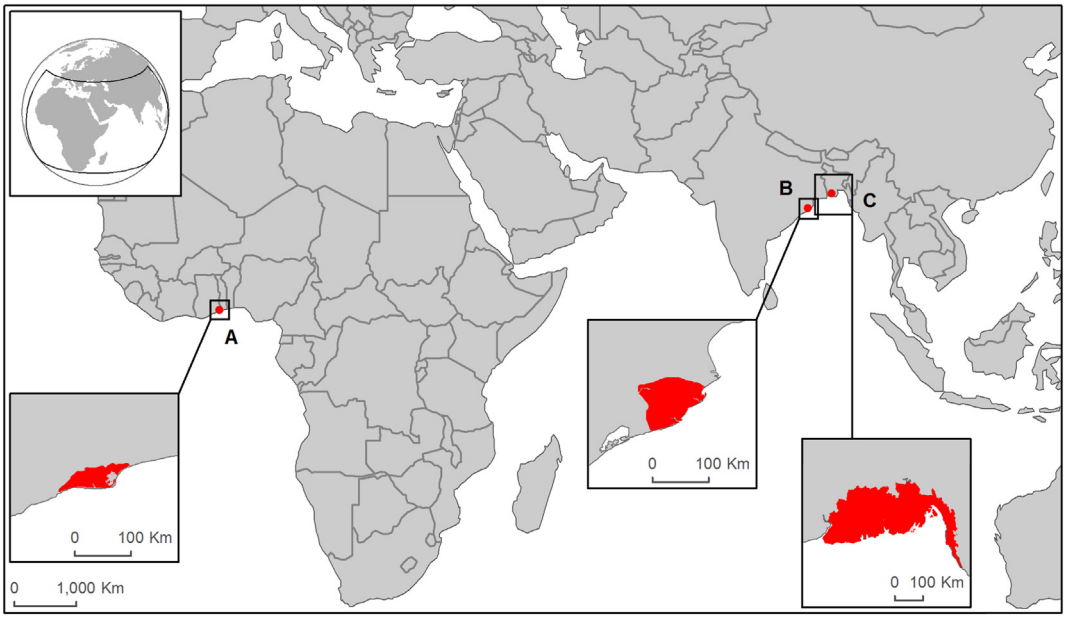

Fig. 1. Map of the DECCMA study deltas (A: Volta Delta, Ghana; B: Mahanadi Delta, India; C: Ganges-Brahmaputra-Meghna (GBM), India and Bangladesh).

sustainable livelihoods approach (SLA) builds on decades of work on entitlements and endowments. It has been widely used to document poverty and wellbeing in the context of shocks and stresses (Carney, 1998; Chambers and Conway, 1992). The SLA offers a visual and practical framework to categorise adaptations around the different forms of capitals that are used to generate income and support livelihoods (DfID, 1999). The five capitals used in the SLA relate to people's stocks of/access to: i) the natural environment (*natural capital*); ii) health, education and physical wellbeing (*human capital*); iii) financial resources (*financial capital*); iv) physical assets and infrastructure, such as houses, cars, phones (*physical capital*); and v) access to social networks and community support (*social capital*).

The Hyogo and Sendai Frameworks (UNISDR, 2005; UNISDR, 2015) categorise actions that address the second aim of adaptation, DRR. These frameworks respond to decades of research into DRR that finds that disasters do not happen on their own – they are created through people's susceptibility and exposure to hazards (Pelling, 2001; World Bank and United Nations, 2010). The frameworks acknowledge that susceptibility and exposure arises from a lack of action in four time steps: i) *long term risk mitigation*, such as managing land or infrastructure to reduce risk; ii) *hazard preparedness*, i.e. preparing for specific hazards, for example through developing risk management plans; iii) *response*, timely action taken immediately before, during or immediately after a hazardous event, e.g. evacuation or going to a shelter; and iv) *recovery and rehabilitation*, i.e. returning to normality after a disaster, such as search and rescue, or rebuilding post disaster.

A third framework, the Millennium Ecosystem Assessment (MEA, 2005), categorises actions that address the third aim of adaptation, building social-ecological resilience. The MEA recognises the value of ecosystems and the services that they provide. Following CGIAR (2014) and Walker and Salt (2012) we define ecosystems services as the combined actions of natural processes that perform functions of value to society. Since the MEA, ecosystems are broadly recognised as delivering four main types of services: i) provision of food, water, building materials and protection of direct use to people (*provisioning services*); ii) maintenance of a diversity of species (e.g. bee and bird populations to fertilise plants) to support other ecosystems (*habitat services*); iii) maintenance of healthy planetary systems e.g. trees to regulate the climate and air quality (*regulating services*); and iv) aesthetic, spiritual, mental health, and cognitive development services (*cultural services*). By using the MEA in conjunction with the SLA, the interrelationships between natural resources and human wellbeing are recognised. As such, this approach addresses criticisms of the SLA that relate to the concept of 'natural capital', notably, that by suggesting ecological processes are a form of capital, trading them for another form of capital, for monetary or other gain, is without consequence (Sneddon, 2000).

Collectively, these three theoretical frameworks allow us to consider adaptation options at multiple spatial scales, across multiple environments (from human to natural), and at multiple administrative scales (household to national). To allow us to identify and document adaptations we use all three frameworks (Fig. 2), recognising 13 classes of adaptation. Although we document adaptations using deltas as an example, these classes of adaptation could apply anywhere.

As with any typology, there are inevitably overlaps between categories. To address this issue, we have slightly modified the focus of some of the 13 classes, which are outlined in greater detail in Table 1. For example, to address areas of potential duplication between 'natural capital' and 'provisioning services', we include 'natural capital' adaptations only where the adaptation actively influences livelihoods and relates to land access and ownership. For example, natural capital adaptations may include land reclamation and redistribution (to the poor or other groups) or fishing zones with associated fishing rights. In contrast, adaptations included in 'provisioning services' relate to the production of goods and services by the land. These adaptations may include the use of climate tolerant crops or the provision of seed banks. The following section applies this framework to first identify current adaptation actions in deltas, and then to create directions for policy that explicitly show the trade-offs between the 13 different classes.

3. Identifying long term adaptation policy directions for deltas

With a view to creating a set of adaptation policy directions for deltas, a three step process was adopted: i) identify current policy-led adaptation actions in deltas in Ghana, India, and Bangladesh (using the framing method in Section 2); ii), create narratives of adaptation policy directions; and iii) highlight adaptation trade-offs inherent in each policy direction.

3.1. Step 1: Identify current policy-led adaptation actions in deltas

Adaptation actions were identified using an inventory of observed adaptations, delta-wide adaptation policy analyses, and a literature

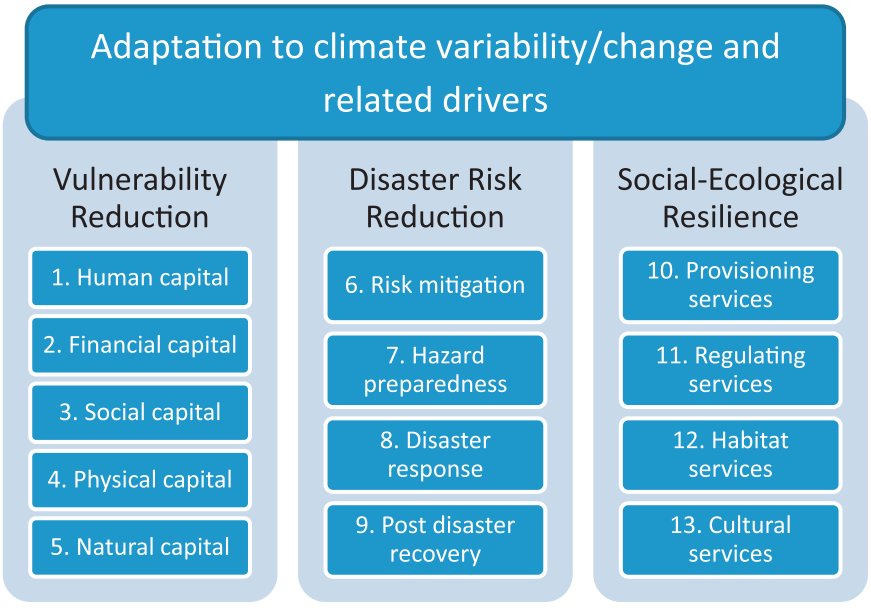

Fig. 2. Classes of adaptation.

Table 1
Description of the 13 classes of adaptation.

Broad objective of adaptation	Class of adaptation	Description of plausible adaptations
Addressing drivers of vulnerability	1. Financial capital	Changes in flows of money and savings that households have available, including loans and insurance
	2. Human capital	Changes in skills, health and ability to labour of members of a household
	3. Social capital	Changes in networks, relationships and membership of groups that households can use
	4. Natural capital	Changes in land ownership and access to natural resources and storage facilities
	5. Physical capital	Changes in infrastructure and goods such as tools and equipment that households can use to increase productivity and non-productive assets of the households (e.g. house material)
Disaster risk reduction	6. Managing long term risk	Efforts to build physical and social infrastructure that mitigate the worst impacts of an event. These can be one off activities, for example, building a sea wall, cyclone shelters, or on-going initiatives, e.g. developing flood risk management plans or relocating communities.
	7. Preparedness	Efforts to ensure communities are ready to respond to an event. These activities take place cyclically, for example, ensuring sea walls are maintained, practicing evacuation drills, or testing early warning systems.
	8. Response	Efforts to ensure affected households, communities, business and services receive appropriate assistance during and immediately following an event, e.g. evacuation support, first aid medical supplies, emergency responders
	9. Post disaster recovery and rehabilitation	Efforts to ensure affected households, communities, business and services are able to rebuild following an event, e.g. rehousing, reconstruction, etc.
Landscape/ecosystem resilience	10. Provisioning services	Changes in ecosystem goods, quality or productivity that can be directly consumed, such as food, water, raw materials (e.g. fibre, biofuel, ornamental items), but also adaptations that enhance these services such as the use of irrigation and fertiliser
	11. Regulating services	Changes in the services that keep the wider planetary systems (such as the atmosphere, cryosphere, oceans) functioning and include the regulation of climate, air, nutrient cycles and water flows; moderation of extreme events; treatment of waste – including water purification; preventing erosion; maintaining soil fertility; pollination; and biological controls, such as pests and diseases.
	12. Habitat services	Changes in the habitats that maintain the life cycles of species or maintain genetic diversity, through quality and quantity of suitable habitats. In turn, these habitats underpin the health of provisioning and regulating services.
	13. Cultural services	Changes in aesthetic, recreational and tourism, inspirational, spiritual, cognitive development and mental health services provided by ecosystems.

search on transformational adaptation. First, to generate evidence of observed adaptations, we conducted a keyword search using ISI Web of Science. Each delta team employed specific search terms appropriate to the type of hazard they experienced. For example, Bangladesh used terms such as "Climat*", "Adapt*", "Cyclon*", "Flood*", "Salin*" coupled with the term "Bangladesh". Papers were deemed suitable for inclusion if they documented observed (and not theoretical) examples of adaptation, included a study area that was within the boundaries of the DECCMA deltas, had been peer-reviewed, and were published in English. To identify articles from the grey literature (e.g. NGO reports) we used a snowballing method where we discussed the findings of the peer-reviewed literature search with country experts who then sought out relevant grey literature (Hagen-Zanker and Mallett, 2013). The output of these searches generated an inventory of 122 adaptations that included strategies such as post disaster mobile water treatment plants or training on new farming methods. Of these, 93 documents relate to the GBM delta (85 from Bangladesh and 8 from the Indian Bengal Delta), 14 refer to the Mahanadi, and 15 to the Volta.

Second, each DECCMA country team conducted a review of current and proposed adaptation policy in the study areas (Dey et al., 2016.; Ghosh et al., 2016; Haq et al., 2015; Hazra et al., 2016; Mensah et al., 2016). Thirty-one policy documents from the GBM were included in the review (21 from Bangladesh and 10 from the Indian Bengal Delta); 21 policy documents from the Mahanadi were included; and 18 from Ghana. Third, a literature search was undertaken on transformative adaptation to document the types of adaptations that could be considered radical, new and of a scale or intensity so the whole deltaic system is transformed, either socially, physically, or both (Kates et al., 2012; Vincent, 2017).

All data were analysed consistently within the three DECCMA deltas using a data collection and analysis template, developed by Tompkins et al. (2010) and described in Tompkins et al. (2017). For each adaptation found in the literature, information categorised based on five core questions asked by (Smit and Pilifosova, 2001): Form: what does the adaptation look like?; Purposefulness: why is the adaptation being undertaken?; Provider/beneficiary: who is providing the adaptation and who is benefiting from it?; Timing: is the adaptation occurring in response to or in anticipation of climate change?; Function/effects: what is the broad aim of in terms of addressing drivers of vulnerability, reduce disaster risk, and/or building landscape/ecosystem resilience. As with all methods, this approach has its limitations, notably, only published works are included and as such, adaptations that have not been reported in the literature may have been missed. The list of adaptation interventions therefore may not reflect all the adaptations that are currently happening in deltas.

The adaptations identified included actions undertaken autonomously by households, non-governmental organisations (NGOs) and governments. As the focus of this method is on policy-led adaptation the household adaptations were removed, and the remaining government and NGO-led adaptations were grouped into 67 discrete types, using the high level categorisation of adaptations set out in Table 2. The next step describes the four different policy directions that policymakers may choose to follow. For each of the four policy directions, the adaptations in Table 2 are either more/less important, or do not feature at all.

3.2. Step 2: Creating narratives of the adaptation policy directions

In creating the directions for policy, we note two key limiting variables that influence adaptation policy choice: the investment cost of the adaptation, and the extent to which significant policy change, and hence political effort, is required (Klein et al., 2014; Mimura et al., 2014; Smit et al., 2001). The adaptations in Table 2 reflect a diversity of costs and effort required. They range from minimal to high cost, and from requiring a small or incremental change to a significant change from the status quo. This spectrum of cost, and willingness to commit to substantial change from the status quo have been recognised in earlier research on infrastructure systems (Hall et al., 2016; Hickford et al., 2015) and the same approach was used here to consider what might drive governments to adopt different adaptation actions (Fig. 3).

Drawing on this four quadrant categorisation, a set of distinctly different cost and effort sets of plausible adaptation directions are developed for deltas.

A. *Minimum Intervention* (*low investment/low commitment to policy change*) is a no-regrets strategy where the lowest cost adaptation

Table 2
Current or planned policy-led adaptations in DECCMA deltas.

Broad objective of adaptation	Adaptation actions
Addressing drivers of vulnerability	1. Promote livelihood diversification (farming) 2. Switch livelihoods (from farming to off-farm) and develop non-farm industry 3. Promote livelihood diversification (fishing) 4. Promote livelihood diversification - off-farm activity 5. Livelihood diversification – fishing 6. Education for non-farm livelihoods, based within the delta (e.g. STEM livelihoods) 7. Education for non-farm livelihoods, based outside the delta (e.g. STEM livelihoods) 8. Agricultural extension to provide training on how to increase income at the household level, e.g. by providing new farming or fishing techniques. 9. Availability of business and household loans at government level 10. Incentives for migration to economic expansion areas 11. Financial incentives to relocate outside of the worst affected parts of the delta 12. Promote private sector investments in eco-tourism through economic incentives 13. Establish agriculture and fisheries based insurance schemes 14. Post-harvest production and storage at local level (e.g. farmer level) 15. Develop and use open spaces, green belts and other ecologically sensitive areas for alternative livelihoods such as urban farming 16. Use of climate resilient farming techniques 17. Farmer led cooperatives that reduce the cost of production/distribution 18. Improving access to markets for all, including infrastructure and training 19. Fishing zones/rights for small-scale fishers 20. Land reclamation and redistribution (to the poor or other groups)
Disaster risk reduction	21. All-Risk-changing-modifications to homes (e.g., height of foundations/walls/floors, climate resilient cluster housing) and local facilities (e.g., raise water sources and sanitation facilities above flood levels) through funding, loans and new building standards and codes 22. Raise land using controlled sedimentation 23. Beach nourishment 24. Land zoning, including no build zones 25. Education at school level re. responsivities for DRR management e.g. evacuation training 26. Active stakeholder engagement in design and delivery of DRR 27. Communication and information re. individual roles and responsibilities re DRR 28. Readiness of emergency services to distribute medicines, food and potable water 29. Availability of DRR insurance 30. Rehabilitation and upgrading of reservoirs for water storage (e.g. dredging, raising spillway levels) 31. Funding to reduce risks to agriculture (Government-run Agriculture Disaster Mitigation Fund) 32. Multipurpose shelters including flood and cyclone shelters used in conjunction with early warning systems 33. River/coastal management defence infrastructure (including sea walls, groynes, dikes and polders) 34. Climate-proof grain silos/storage (at national and local level) 35. Ensure food availability during floods (e.g. Floating gardens and hanging vegetable garden) 36. Train community in DRR management 37. Train community in water management 38. Maintain existing infrastructure 39. Initiatives to promote economy recovery, e.g. funding to rebuild damaged economic assets such as ports, roads and grain stores 40. Temporary evacuation 41. Use of emergency responders 42. Secondment of army or national resources 43. Post disaster mobile water treatment plants 44. Post disaster house construction 45. Managed/forced relocation of households from disaster-affected areas
Landscape/ecosystem resilience	46. Climate tolerant crops 47. Changing crop varieties 48. Seed bank for crop diversification 49. Climate tolerant aquaculture (e.g. brackish shrimp) 50. Alternative climate proof grasses for cattle 51. Mixed land use (e.g. polder and freshwater shrimp farm with rice) 52. Changing irrigation and water level management practices to improve agriculture 53. Potable water management 54. Promote saline tolerant trees to prevent erosion around farms and homes 55. Use of agro-chemicals to boost agricultural productivity and treat salinity 56. River course management 57. Mangrove forest planting 58. Agroforestry 59. Afforestation - Promote ecological restoration of degraded and poorly stocked forests 60. Tree planting in public areas 61. Create incentives for investor in tree crops and plantation (tax relief for private sector investment in research and development) 62. Reduce the pressure on forests for wood-fuels by encouraging use of renewable energy 63. No commercial mining in forested areas 64. Afforestation – climate tolerant bamboo 65. Create biological corridors between existing conservation areas to maintain gene flows 66. Promote establishment of protected green spaces with native grass along waterways 67. Conserve wildlife and biodiversity in natural heritage sites including sacred groves, protected areas

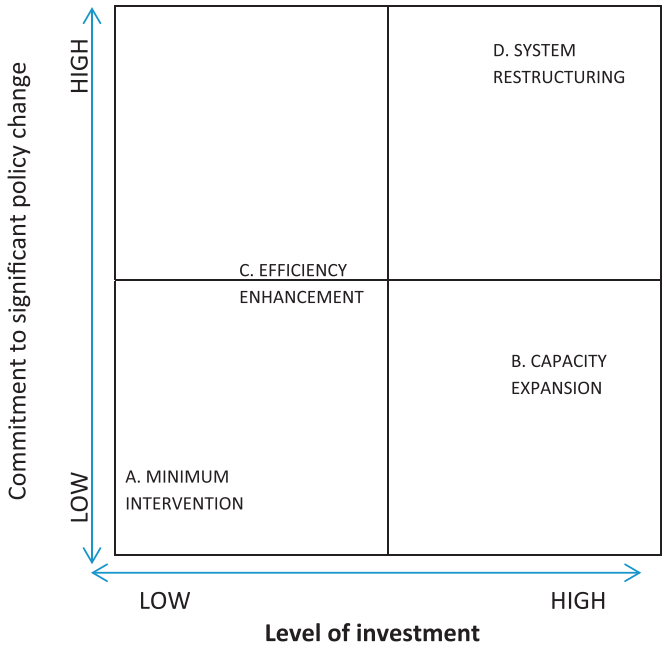

Fig. 3. Drivers of government-led adaptation policy choice.

policies are pursued to protect citizens from some climate impacts. This strategy addresses those areas where maximum impact can be achieved for the lowest cost, requires low levels of commitment to policy change and promotes adaptations that require little investment. This direction reflects either a fundamental preference for a non-interventionist government, or a government lacking ambition or the capacity to act. It may also reflect the position of a government that feels that no further action is required. There is little planning for climate events, instead, the government provides a basic emergency response.

B. *Capacity Expansion* (*high investment/low commitment to policy change*) encourages climate-proof economic growth, but does not seek to make significant change to the current structure of the economy. A high level of investment is required to prepare the economy for future change, but adaptation policy does not aim to reorient the economy, or create significant change. Instead, the focus is on climate proofing industry and enhancing ability to adapt to changes.
C. *Efficiency Enhancement* (*medium investment/medium commitment to policy change*) is an ambitious strategy that promotes adaptation consistent with the most efficient management and exploitation of the current system, looking at ways of distributing labour, balancing livelihood choices, and best utilising ecosystem services to enhance livelihoods and wellbeing under climate change. As this policy direction is about efficiency, it requires less investment than other interventionist approaches (i.e. capacity enhancement and system restructuring). However, there is a reasonable commitment to significant policy change as the system moves toward supporting people to adapt to long term change.
D. *System Restructuring* (*high investment/high commitment to change*) embraces pre-emptive fundamental change at every level in order to completely transform the current social and ecological system, and change the social and physical functioning of the delta system. There is a guiding belief that significant/radical landscape modifications are justified to create long term system restructuring despite the short term costs that may be accrued, among some social groups, or economic sectors. Within this broad policy direction are three possible sub-directions which each seek a different end goal. The first is "*protect*", broadly following the Dutch model with use of extensive protective infrastructure and significant landscape changes to protect the current status quo in terms of livelihoods (VanKoningsveld et al., 2008). Under this policy, land is protected from any further change so that communities can continue to maintain traditional livelihoods such as farming or fishing. The second is "*accommodate*", as is evolving in the Mississippi delta where livelihoods have significantly changed in order to 'live with nature' and there is an aspiration to 'work with nature' to adapt to changes to the natural environment (Day et al., 2014). The third is "*retreat*" or abandonment of the delta in terms of population, for example, through a policy of population and infrastructural relocation (Dun, 2011). All three restructuring policies require a high level of investment and a high commitment to significant policy change.

3.3. Step 3: Exploring adaptation trade-offs

Having developed a conceptualisation of adaptation, collated evidence of adaptation, and designed a contrasting set of adaptation policy directions, the next step is to allocate specific adaptation measures to each direction. To do this, a more nuanced understanding of each policy direction is required where each of the 13 adaptation classes are given relative weights to reflect the relative levels of investment, and political willingness to change. In the context of finite resources, this approach also identifies the trade-offs that occur between the 13 adaptation classes. Due to the complexity of the task, and following Brooks et al. (2005), an expert interdisciplinary group of eight delta research scientists (in the fields of climate change adaptation, engineering, systems modelling, population and development, and geography) were asked to deliberate on the relative investment availability under each policy direction, and to assign weights to reflect this investment (Table 3). Low, medium and high levels of investment were represented by three weights allocated out of 40. Hence direction A (the least costly) is weighted 20; B is weighted 40; C is weighted 30; and, D is weighted 40. These weights constrain the quantities and focus of adaptation under each direction, thus highlighting the investment directions under each scenario. This however, also means that some adaptation measures may be ignored altogether.

The expert group also determined how 'significant policy change' could be represented by allocating the points within each policy direction across the 13 adaptation classes. The points within each adaptation class were allocated using a two stage subjective weighting process. First, for each policy direction, each expert was asked to rank the 13 classes in order of importance. Then, in a collaborative workshop, the experts deliberated on the order of the classes for each policy direction until consensus was achieved. Second, the experts were asked to assign the points available under each policy direction to each of the classes based on their importance. Again, this was done through an open process of deliberation until consensus was achieved. As with any subjective decision making process, the outcome is informed by the knowledge, perceptions and experience of the decision makers. Thus a potential limitation arises.

Using this approach, the least costly policy direction, Minimum Intervention spreads limited resources across six of the 13 classes of adaptation. However, one of the three most ambitious directions, System Restructuring (Retreat) divides more substantial resources across just three classes of adaptation and uses half of its significant resources on post disaster recovery and rehabilitation alone. Using this weighting system it is possible to constrain the relative scope and types of adaptation present in each policy direction to understand where trade-offs occur.

4. Understanding adaptation policy choices in deltas

Using the methods described in Section 3, this section explores more deeply the nature and structure of the adaptation policy directions. The policy directions offer a vision of some of the feasible adaptation futures within deltas, taking into account the main objectives of adaptation, and

Table 3
Weights assigned to policy directions.

Broad objective of adaptation	Class of adaptation	Policy direction					
		A. Minimum intervention	B. Capacity expansion	C. System efficiency	D. System restructuring		
					Protect	Accommo-date	Retreat
Addressing drivers of vulnerability	1. Financial capital	0	8	0	3	15	10
	2. Human capital	5	7	6	3	15	10
	3. Social capital	0	0	6	0	0	0
	4. Natural capital	0	0	4	3	0	0
	5. Physical capital	0	5	0	0	0	0
DRR	6. Managing long term risk	1	4	4	20	10	0
	7. Preparedness	0	2	3	0	0	0
	8. Response	4	2	0	0	0	0
	9. Post disaster recovery and rehabilitation	4	2	0	0	0	20
Landscape/ecosystem resilience	10. Provisioning	6	5	3	10	0	0
	11. Regulating	0	5	1	1	0	0
	12. Habitat	0	0	1	0	0	0
	13.Cultural	0	0	2	0	0	0
	Total investment	20	40	30	40	40	40

the adaptation actions that currently occur in deltas. The impacts of each direction can only be understood through an analysis of the specific adaptation choices that it promotes. To populate the four policy directions, the 67 adaptation types in Table 2 were categorised using the 13 classes of adaptation (see Tables 4–7). Each adaptation can appear in more than one of the policy directions. For example, the adaptation intervention to 'promote private sector investments in eco-tourism through economic incentives', was categorised under "*1. Financial capital – addressing drivers of vulnerability*". It was then assigned to the Capacity Expansion policy direction as it offers a non-farm income generating activity, which sits alongside traditional farm based livelihoods. It was also assigned to the System Restructuring (Accommodate) policy direction as it may enable a complete shift from farm-based to non-farm-based livelihood activities that are more suited to a changed environment. For each of the four policy directions, we detail the adaptation options that might occur within them, highlighting areas that are less important, or that are ignored all together.

4.1. The minimum intervention adaptation choices

Vulnerability is reduced through investing in human capital. There is little or no investment in other forms of capital. Investment in *human capital* may include basic training on how to increase income at the household level, such as learning new farming or fishing techniques. For example, India's Central Rice Research Institute (CRRI) provide support and training to farmers to develop integrated rice-fish farming systems on flood prone land in Odisha (RCDC, 2011) The CRRI also provide training so farmers can grow new varieties of fruit, vegetables and trees. Other similar schemes were reported (see: Ahmed and Garnett, 2011; Sattar and Abedin, 2012; Sterrett, 2011).

DRR is delivered in three ways. First, through simple measures to *address long term risk*, such as training farmers to create floating gardens on flooded land (Practical Action, 2011). Second, through *disaster response* such as temporary evacuation, emergency responders and the secondment of the army or national resources. For example, WWF-India has helped train disaster management teams in West Bengal who receive state support to help the community during extreme events (Danda, 2010). Third, basic services are provided during post *disaster recovery and rehabilitation*, such as post disaster mobile water treatment plants and post disaster house construction for the worst affected households. For example, following Cyclone Komen (2015) the Bangladesh Red Crescent Society (BDRCS) distributed cash grants, 3000 tarpaulins, 30,000 packets of oral rehydration solution and installed two mobile water treatment plants in the worst affected areas (IFRC, 2015).

Ecosystem resilience is delivered through some basic *provisioning services*, which are partially supported through training services such as potable water management. For example, in Bangladesh, UNICEF and the Department of Public Health have introduced pond sand filters (PSFs) along the coastal belt (Ahmed, 2010). There is no support for

Table 4
Adaptation interventions under the minimum intervention direction.

Broad objective of adaptation	Adaptation class	Example of adaptation intervention
Addressing drivers of vulnerability	1. Financial capital	*Not a priority/component not active*
	2. Human capital	• Agricultural extension officer who provide basic training on how to increase income at the household level, such as learning new farming or fishing techniques.
	3. Social capital	*Not a priority/component not active*
	4. Natural capital	*Not a priority/component not active*
	5. Physical capital	*Not a priority/component not active*
DRR	6. Managing long term risk	• Ensure food availability during flood (e.g. Floating gardens and hanging vegetable garden)
	7. Preparedness	*Not a priority/component not active*
	8. Response	• Temporary evacuation • Use of emergency responders • Secondment of army or national resources
	9. Post disaster recovery and rehabilitation	• Post disaster mobile water treatment plants • Post disaster house construction
Landscape/ecosystem resilience	10. Provisioning	• Potable water management
	11. Regulating	*Not a priority/component not active*
	12. Habitat	*Not a priority/component not active*
	13. Cultural	*Not a priority/component not active*

Table 5
Adaptation interventions under the capacity expansion direction.

Broad objective of adaptation	Adaptation class	Example of adaptation intervention
Addressing drivers of vulnerability	1. Financial capital	• Promote private sector investments in eco-tourism through economic incentives • Post-harvest production and storage • Develop and use open spaces, green belts and other ecologically sensitive areas for alternative livelihood such as urban farming • Existence of loans at government level • Incentives for migration to economic expansion areas
	2. Human capital	• Education for non-farm livelihoods, based within the delta (e.g. STEM livelihoods) • Education for non-farm livelihoods, based outside the delta (e.g. STEM livelihoods)
	3. Social capital	*Not a priority/component not active*
	4. Natural capital	*Not a priority/component not active*
	5. Physical capital	• Access to markets for all, including infrastructure, training
DRR	6. Managing long term risk	• Government funds to reduce risks to agriculture (Government run Agriculture Disaster Mitigation Fund) • Establish agriculture and fisheries based insurance schemes • Cyclone/flood shelters, including early warning systems • River/coastal management defence infrastructure(including sea walls, groynes, dikes and polders) • Climate proof grain silos/storage • Ensure food availability during flood (e.g. Floating gardens and hanging vegetable garden)
	7. Preparedness	• Maintain existing infrastructure (e.g., coastal embankments, river embankments and drainage systems, urban drainage systems)
	8. Response	• Emergency aid provision • Provision to ensure business and economic activities that support the economy receive immediate attention • Critical infrastructure protection
	9. Post disaster recovery and rehabilitation	• Initiatives to get the economy running quickly, e.g. funds available to rebuild damaged economic resources such as ports, roads and grain stores
Landscape/ecosystem resilience	10. Provisioning	• Potable water management • Climate tolerant crops (Saline tolerant crops; Use of drought and heat resistant crop varieties – e.g. drought tolerant peppers) • Using different crop varieties • Climate tolerant aquaculture • Promote saline tolerant trees to prevent erosion around farms and homes • Seed bank for crop diversification • Alternative climate proof grasses for cattle
	11. Regulating	• Use of agro-chemicals • Create incentives for investor in tree crops and plantation (tax relief for private sector investment in research and development
	12. Habitat	*Not a priority/component not active*
	13. Cultural	*Not a priority/component not active*

other ecosystem services. See Table 4, for details of the specific adaptation interventions.

4.2. The capacity expansion adaptation choices

Vulnerability reduction is the main focus of this policy direction with the prime focus is on improving *financial capital*. This is done at the household level, for example training on post-harvest production and storage (Chowdhury et al., 2011) and government and NGO provided loans (Aveh et al., 2013; Nukpezah and Blankson, 2017). For example, micro-credit based by the World Health Organization (WHO) in the Volta have shown a reduction in poverty among women farmer-entrepreneurs. Vulnerability reduction is also done at the government level, for example, by encouraging private sector investment in ecotourism, which is a policy goal in Ghana (Government of the Republic of Ghana, 2013). There is also an emphasis on *human capital* as the government invests in training that in turn will ensure households are able to better participate in the non-farm economy (Haggblade et al., 2010) and on *physical capital* by ensuring that appropriate infrastructure exists to support economic growth e.g. roads, storage, rural electricity (Deichmann et al., 2009; Sharma, 2007).

DRR focuses on *long term risk mitigation* through hard and soft measures. For hard DRR there might be a focus on the provision of river/coastal infrastructure to protect economically important areas, for example, the World Bank recently invested USD 400 million to improve polder embankments in economically important areas of Bangladesh (World Bank, 2013). For soft DRR, preparedness and risk mitigation, for example through agriculture and fisheries based insurance schemes (Government of the People's Republic of Bangladesh, 2009); *Post-disaster recovery* efforts focus on getting the economy functioning quickly after disasters and reducing the impact of natural hazards on economic sectors. For example, rapidly releasing funds to rebuild damaged economic resources such as ports, roads and key grain stores.

Ecosystem resilience is delivered through investment in *provisioning services*. This is to enable income from food and water production under future climate change, for example, by using saline tolerant crops that can withstand coastal flooding (Islam et al., 2016). There is also a focus on *regulating services*, for example, the use of agro-chemicals or creation of private sector incentives for tree planting. See Table 5, for more details of the specific adaptation interventions.

4.3. The efficiency enhancement adaptation choices

Vulnerability is reduced by focusing on human and social capital at the household and community level. In terms of *human capital*, livelihood diversification in farming is promoted as is the teaching of climate resilient farming and post-harvest production methods (White et al., 2016). In terms of *social capital*, local farming and fishing cooperatives ensure maximum production benefits. Finally, by improving access to *natural capital*, for example through fishing permits, households are able to make the most efficient use of income generating resources (Monirul Islam et al., 2014).

DRR is provided through investments in long term risk management using relatively low cost interventions such as early warning systems and cyclone shelters (Danda, 2010; Roy et al., 2015), development of building codes for buildings in at risk areas and no build zones and government funds to reduce risks to agriculture, such as government run Agriculture Disaster Mitigation Funds. There is also a focus on

Table 6
Adaptation interventions under the efficiency enhancement direction.

Broad objective of adaptation	Adaptation class	Example of adaptation intervention
Addressing drivers of vulnerability	1. Financial capital	*Not a priority/component not active*
	2. Human capital	• Use of climate resilient farming techniques • Livelihood diversification (farming) • Livelihood diversification (fishing) • Livelihood diversification - off-farm activity • Post-harvest production and storage at local level (e.g. farmer led)
	3. Social capital	• Farmer led cooperatives that reduce the cost of production/distribution
	4. Natural capital	• Fishing zones/rights for small-scale fishers
	5. Physical capital	*Not a priority/component not active*
DRR	6. Managing long term risk	• Cyclone/flood shelters, including early warning systems • All-Risk-changing-modifications to homes (walls/floors, etc.) - through funding and new building codes • Rehabilitation and upgrading of reservoirs for water (e.g. dredging, raising spillway levels) • Government funds to reduce risks to agriculture (Government run Agriculture Disaster Mitigation Fund • Ensure food availability during flood (e.g. Floating gardens and hanging vegetable garden) • Land zoning/no build zones
	7. Preparedness	• Education at school level re. responsivities for DRR management e.g. evacuation training • Active stakeholder engagement in design and delivery of DRR • Communication and information re. individual roles and responsibilities re DRR • Readiness of emergency services to distribute medicines, food and potable water
	8. Response	*Not a priority/component not active*
	9. Post disaster recovery and rehabilitation	*Not a priority/component not active*
Landscape/ecosystem resilience	10. Provisioning	• Mixed land use (e.g. polder and shrimp farm with rice) • Changing irrigation and water level management practices to improve agriculture
	11. Regulating	• Mangrove forest planting • Promote the adoption of farm forestry practices, which include managing trees on farms, farm boundary planting and agroforestry systems (Ghana) • Promote ecological restoration of degraded and poorly stocked forests using appropriate reforestation/restoration techniques(ie enrichment planting, Assisted Natural Regeneration) • Tree planting in public areas • Reduce the pressure on forests for wood-fuels by encouraging use of renewable energy • Afforestation – climate tolerant bamboo
	12. Habitat	• Create biological corridors between existing of conservation areas to maintain gene flows • Promote establishment of protected green spaces with native grass along waterways
	13. Cultural	• Conservation of wildlife and biodiversity in natural heritage sites including sacred groves, protected areas • Protect sacred groves

preparedness. Communities are trained to prepare for events through relatively low cost initiative, such as DRR education at school evacuation training and stakeholder engagement in DRR plans (Sunderban Social Development Centre, 2012; WWF-India, 2010). There is little emphasis on *response* or *recovery*.

Ecosystem resilience is a priority as it supports efficient management and exploitation of the delta system. All four ecosystem services are recognised as contributing to wider system efficiency and all are the focus of government interventions. The focus is on low cost interventions. In terms of *provisioning*, mixed land use and irrigation are promoted (UNDP Bangladesh, 2011). In terms of *regulating*, tree planting, including mangroves, is the main focus (APOWA, 2012; DasGupta and Shaw, 2013; Iftekhar and Takama, 2008; Kinney et al., 2012). In terms of *habitat*, biological corridors are created, as are green spaces with native grass along waterways. Finally, in terms of *cultural* services the conservation of wildlife and biodiversity including sacred groves is promoted. See Table 6, for more details of the specific adaptation interventions.

4.4. The system restructuring adaptation choices

4.4.1. System restructuring – Protect

This policy direction aims to significantly change the natural system to make sure that traditional, agricultural based livelihoods are protected from climate impacts. *Vulnerability* is reduced by focusing on financial, human and natural capital. In terms of *financial capital* the green belt is used for farming so productivity can be maximised. In terms of *human capital*, climate resilient farming techniques are promoted, and in terms of *natural capital*, land is redistributed to poorer farmers (Devine, 2002) and small-scale fishers receive fishing rights. *DRR* is the main focus with all emphasis on managing *long term risk* through, for example, raising of land elevation using controlled sedimentation (Schiermeier, 2014), the creation of dikes to manage flood water, no build zones, land zoning and massive investment in river/coastal defence infrastructure. Specifically, there is significant investment in river/coastal defence infrastructure to protect the built environment including industry. This would attempt to replicate the success of the Delta Project in the Netherlands (VanKoningsveld et al., 2008) *Ecosystem resilience* is a priority as the aim of this policy direction is to allow traditionally based agricultural livelihoods to continue. In terms of *provisioning*, significant land use changes and use of climate tolerant crops allow farming to continue. In terms of *regulating*, river course management and strict rules around forest use also allow farming to continue. See Table 7, for more details of the specific adaptation interventions in the three sub directions.

4.4.2. System restructuring – Accommodate

This policy direction aims to significantly change livelihoods (i.e. move away from traditional agricultural activities) to ensure the population can remain in the delta despite environmental change and sudden environmental shocks. *Vulnerability* is reduced by significantly focusing on financial and human capital. In terms of *financial capital*,

Table 7
Adaptation interventions under the system restructuring direction.

Broad objective of adaptation	Adaptation class	Example of adaptation intervention		
		Protect	Accommodate	Retreat
Addressing drivers of vulnerability	1. Financial capital	• Develop and use open spaces, green belts and other ecologically sensitive areas for farming	• Promote private sector investments in eco-tourism through economic incentives • Development of non-farm industry	• Financial incentives to relocate outside of the delta
	2. Human capital	• Use of climate resilient farming techniques	• Education for non-farm livelihoods, based within the delta	• Education for non-farm livelihoods, based outside the delta
	3. Social capital	*Not a priority/component not active*	*Not a priority/component not active*	*Not a priority/component not active*
	4. Natural capital	• Land redistribution (to the poor or other groups) • Fishing zones/rights for small-scale fishers	*Not a priority/component not active*	*Not a priority/component not active*
	5. Physical capital	*Not a priority/component not active*	*Not a priority/component not active*	*Not a priority/component not active*
DRR	6. Managing long term risk	• Raise land using controlled sedimentation • Beach nourishment • Land zoning, including no build zones • River/coastal management defence infrastructure (including sea walls, groynes, dikes and polders)	• Cyclone/flood shelters, including early warning systems • Train community in DRR management • Train community in water management • All-Risk-changing-modifications to homes (e.g., height of foundations/walls/floors, climate resilient cluster housing) and local facilities (e.g., raise water sources and sanitation facilities above flood levels) through funding, loans and new building standards and codes	*Not a priority/component not active*
	7. Preparedness	*Not a priority/component not active*	*Not a priority/component not active*	*Not a priority/component not active*
	8. Response	*Not a priority/component not active*	*Not a priority/component not active*	*Not a priority/component not active*
	9. Post disaster recovery and rehabilitation	*Not a priority/component not active*	*Not a priority/component not active*	• *Example absent from the data but could include government supported relocation of people outside the delta following an event*
Landscape/ecosystem resilience	10. Provisioning	• Mixed land use (e.g. polder and shrimp farm with rice) • Changing irrigation and water level management practices to improve agriculture • Climate tolerant crops (Saline tolerant crops; Use of drought and heat resistant crop varieties – e.g. drought tolerant peppers) • Using different crop varieties • Climate tolerant aquaculture	*Not a priority/component not active*	*Not a priority/component not active*
	11. Regulating	• River course management • Reduce the pressure on forests for wood-fuels by encouraging use of renewable energy • No commercial mining in forested areas	*Not a priority/component not active*	*Not a priority/component not active*
	12. Habitat	*Not a priority/component not active*	*Not a priority/component not active* (*although new habitat may be created*)	*Not a priority/component not active* (*although new habitat may be created*)
	13. Cultural	*Not a priority/component not active*	*Not a priority/component not active*	*Not a priority/component not active*

there is an effort to promote non-farm industry within the delta, such as private sector investments in eco-tourism through economic incentives. *DRR* focuses on *managing long term risk*. There is also a focus on infrastructure that allows people to remain in potentially dangerous locations, such as early warning systems and cyclone/flood shelters (Lumbroso et al., 2017; Paul, 2009). *Ecosystem resilience* is not a priority as land is not used for provisioning. There is no drive to protect current agriculture.

4.4.3. System restructuring – Retreat

This policy direction aims to encourage population movement out of the more vulnerable parts of the delta. *Vulnerability* is reduced by significantly focusing on *financial* and *human* capital. This may include financial incentives to relocate outside of the delta and farmer investment in training for new non-delta livelihoods. *DRR* focuses on *post disaster recovery and rehabilitation*, specifically, the promotion of relocation outside of the delta following an event. *Ecosystem resilience* is not a priority as land is not used for provisioning. However, new habitats may be created as an incidental impact of the policy.

5. Discussion and conclusion

In this paper, we asked: what adaptations are currently occurring in deltas?; what are possible future directions for adaptation policy?; and, what are the trade-offs associated with each policy direction?

For the first time, we have generated a set of observed adaptations that are occurring in three distinct deltas, but which are also generalizable across deltas worldwide. Adaptations are grouped around three main objectives: (1) actions to reduce socio-economic vulnerability; (2) actions that address disaster risk reduction; and (3) actions that affect social-ecological resilience. In this analysis, we do not reflect on the 'success', 'failure' or 'desirability' of the adaptations, but simply identify what is happening. However, this raises an important research question: what are the short-term and long-term impacts of these adaptations on households and the wider delta? And, are adaptations that

we are observing today suitable for the future when climatic and other conditions may be very different? Understanding these questions is recommended for future research and DECCMA will also try to provide a quantitative answer.

Adaptation actions rarely occur in isolation. More often packages of adaptation measures developed, implemented and evaluated in response to different needs and priorities of nations (EEA, 2014), and these packages of adaptations are likely to reflect policymakers' commitment to both investment and significant change. In this paper, we have developed a method to identify suites of adaptation policies. By recognising both the drivers and constraints on the development of policy (levels of investment and political will to implement change), we have been able to define seven alternative sets of adaptation policy choices that cover a range of possible future states in many deltas. These seven futures also make explicit the trade-offs that occur when policymakers prioritise different aspects of adaptation. As with any work that attempts to identify plausible and realistic bundles of future choices, this research is constrained by current thinking about the nature and scope of adaptation present in deltas today. Indeed, by basing the future policy directions on current and planned adaptation choices we limit the adaptation set to what is known. However, we start to move beyond this by exploring what transformative adaptation might look like in deltas. As a next step in this research, these options can be taken to a range of delta stakeholders combined with other analysis of the future. This will promote further insight on adaptation choices and their implications and refine the choices presented here. This includes application to specific deltas and comparison with the policy process where possible. For instance, the first Bangladesh Delta Plan 2100 (BDP2100) is under preparation and the draft is now in circulation for expert comments (GEC, 2017). As a living plan, the methods described here can potentially provide a reflective approach to develop the BDP2100 into the future.

In answering these questions, we are able to reflect on the implications of adaptation policy choices for deltas where there are uncertain future socio-economic development trajectories, to support policymakers' decisions on the trade-offs necessary to follow their normative goals. This method represents a possible way forward for the global stocktake of adaptation under the Paris Agreement, as it identifies an approach to documenting observed adaptation, as well as giving a vision of possible sets of future adaptation options. Instead of providing a silver bullet this is a way that countries can consider adaptation in a way that suits their geopolitical context and can address their normative goals, expressed as their development aspirations.

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